



An Assessment of Sawmill Wood Waste Availability for Use in Gasifiers in Akure, Ondo State, Nigeria

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Abstract

This study adopts a descriptive research design and employs a mixed-methods approach, combining both primary and secondary data, to assess wood waste generation and management techniques in sawmills across Ondo State, Nigeria. The objective was to evaluate the availability of wood waste and its potential utilization as feedstock for mini-grid gasifiers to generate electricity from renewable sources. Data were collected through surveys, observations, and analysis of sawmill operations. The findings revealed that wood waste comprised residues from the primary conversion of logs, with sawdust contributing the largest quantity. Sawmills in Akure South, with the highest log conversion capacity, contributed the largest volume of wood waste. On average, wood waste generation (WWG) was 44% per log, while lumber recovery (LR) was 56% per head rig, with variations linked to factors such as log shape, size, and conversion techniques, indicating inefficient log conversion in the state. Additionally, wood waste management practices were inadequate, with lumber cut-offs, slabs, and bark sold at a low value and sawdust often disposed of cheaply for domestic use. This study confirms that wood waste can be efficiently utilized as feedstock in mini-grid gasifiers, providing a sustainable solution for electricity generation in Akure, Ondo State.

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Keywords

Gasifier technology; lumber recovery; Renewable energy; sustainable forestry; waste management

1. Introduction

There is an increasing research interest in biomass as an important renewable and environmentally friendly fuel for generating electricity due to uncertainty in the energy market and the problems of greenhouse gas emissions (Gratitude et al., 2019). Utilizing wood waste as biomass to produce bioenergy has the potential to be a very beneficial solution that will guarantee a sustainable energy source while also lessening the environmental impact of the building sector (Maier, 2022; Xie et al., 2023). The renewed interest in the use of renewable sources of energy in Nigeria was

stimulated by the deficit in power generation and the tremendous surge in its population from 88 million in 1990 to over 200 million in 2020 has resulted in more demand for energy (Akintande et al., 2020). The electric load demand in the country is estimated to be 20,000 MW only, an average of 4,156.5 MW was generated in March 2020, and the Association of Nigerian Electricity Distributors (ANED), the umbrella body of Electricity Distribution Companies, (DisCos) has estimated that Nigeria requires 30,000 megawatts of electricity generation to meet the current demand of electricity by consumers (Izuora, 2022). The shortfall in power supply in the country has negatively affected the national economy and destabilised the domestic and industrial sectors as well as other key sectors such as telecommunication, health, transport, and education. Most homes, universities, and companies generate their electricity, “thereby creating a diesel/ petrol driven economy”. The high cost of energy made some companies fold up while others are in the stage of financial comatose. Although the power sector reform report proposed an increase in power generation from 5,000 MW in 2014 to 40,000 MW by 2020 Oladipo et al. (2018), this goal seems unachievable due to different disruptions and maintenance problems with the hydro and thermal stations. Most of the hydro-power plants are affected by seasonal fluctuations in water level, coupled with the challenges of obsolete equipment and disrupted operation at the thermal stations occasioned by irregular gas supply due to vandalism of gas pipelines. Therefore, there must be decentralization of power generation by adapting mini-grids suitable for different locations.

Nigeria generated an estimated 1,000,000 cubic meters of wood waste annually between 2009 and 2010, according to studies by Sambo (2009), Ogunwusi (2014), and Owoyemi et al. (2016). Of this, sawdust accounted for approximately 1.8 million tons each year, translating to around 4,931.51 tons daily (Sambo 2009; Owoyemi et al., 2016; Akhator et al., 2017). In 2014, Owoyemi et al. (2016) estimated Nigeria’s wood waste production at about 104,000 cubic meters per day. Additionally, Okedere et al. (2017) estimated annual sawdust production in southwestern Nigeria alone at 526,650 metric tons. This research is an innovative method for assessing the availability of wood wastes for co-generating electric energy in Ondo State and its environment. Ondo State which is one of the major wood processing states in Nigeria has large quantities of industrial wood wastes because of the high demand for wood products with rapid demographic growth. There were 223 sawmills in Ondo State in 1983, constituting about 21% of the total number of sawmills in Nigeria (Alviar, 1983). The continuous increase in the number of sawmills in the State stabilised the position of Ondo State as one of the largest lumber-producing states in Nigeria. With the present trend of log exploitation exceeding the rate of afforestation and reforestation, there is an imminent wood shortage which can only be averted by improved wood conversion and utilization to ensure that optimum benefit is derived from every wood. Maximizing the volume of lumber recovered from logs with a small quantity of waste will increase sawmills' profitability (Rawat et al., 2023). The factors for measuring the conversion efficiency of a mill include lumber recovery factor (LRF), speed of manufacturing, and grade of recovery (Alagbada et al., 2021). The LRF indicates the quantity of lumber per unit volume of log, it is defined as the ratio of actual board feet (BF) of lumber recovered per unit volume of log processed. Lumber yield is strongly influenced by log form, log quality, and sawmill characteristics such as the types of machines. The grade of recovered wood is important in the assessment of efficiency in that there may be irregularities in lumber dimension due to improper or faulty sawing and this will affect the unit cost of lumber and its utilization. In Ondo State, improper handling of wood waste poses a major environmental risk. Wood waste management practices, which include the collection, disposal, recycling, and reuse of wood waste, are ineffective and inadequate, as evidenced by the obvious disposal of wood waste on streets, in water bodies, and open air. As a result, there will be a serious threat to the sustainability of Nigerian timber forests, human health, and environmental balance.

The substantial reliance on non-renewable fossil fuels in global energy production and consumption has proven to be a significant obstacle to achieving sustainable development goals (Kanwal et al., 2022; Jie et al., 2023; Kocak et al., 2023). Electricity production has been the largest source of emission reductions, with the shift in electricity generation from coal to gas and, in the past decade, to renewable energy (RE) (Caselli et al., 2021). Hence, the utilization of wood waste is a means to improve the management of wood waste. Therefore, the objective of this study was to determine the availability of wood waste across different sawmills in Ondo State that could be used as feedstock in an electricity mini-grid power plant at the Federal University of Technology, Akure. The findings from this assessment provided stakeholders and energy experts with information that further reveals the potential of academic

institutions producing RE from the abundance of wood wastes to support national climate goals. The adoption of renewable energy by different institutions becomes essential for reducing their environmental footprint and aligning with Sustainable Development Goals (SDGs) 7 (Affordable and Clean Energy) and 13 (Climate Action).

2. Materials and Methods

This study was conducted to assess the availability of wood wastes in Ondo State to ascertain the sustainability of feedstock production for a gasifier plant designed at the Federal University of Technology Akure for generating electricity. Ondo State is situated in the South-western part of Nigeria ($5^{\circ} 45' N-8^{\circ} 15' N$, $4^{\circ} 45' E-6^{\circ} 00' E$), (Fig. 1). The state has 18 local government areas (LGAs) with a population of about 3,441,024 according to the 2006 population census and a land area of about 14,606 km² (NPC, 2006; Omonijo and Matzarakis, 2011). The State has a tropical wet-and-dry climate with an annual rainfall range of 1,500 mm to 2,000 mm in the derived savannah and humid forest zones, respectively. Ondo State is one of the major wood processing states in Nigeria. This is a result of the availability of forest resources feeding its numerous sawmills and other wood processing industries.

2.1 Data collection

For the assessment of wood waste availability, primary data on the distribution of sawmills and wood industries in the State were collected from the 2023 records of the Ministry of Environment and Forestry Ondo State, Nigeria. Structured questionnaires were designed and administered to loggers, sawmills, and machine and plant operators in 23 mills across the four selected local government areas (Table 1), to assess the level of waste generation, volume recovery from a typical log, production capacity, and waste management techniques. Measurements were taken before and after the conversion of logs to determine volume recovery and wastes generated from a typical log.

Data extracted from the questionnaires include the location of mills, number of head rigs per mill, types of machines, method of saw doctoring, machine maintenance, and strength of manpower. Information was collected from small, medium, and large-sized mills. Still, for convenience in the statistical analysis of data, only fifteen small-sized mills were selected for this particular study on log conversion patterns, LR, time efficiency, idle working time, and saw geometry. Measurements were taken on ten random logs per sawmill.

The volume (V) of logs was determined by applying data of measured girth at both ends of the log as well as the length of the log to the Smalian formula in Equation 1:

$$V = \frac{L}{2}(Cb + Ct) \quad (1)$$

Where V , L , Cb , and Ct are the length of log (m), the cross-sectional area at the base, and the cross-sectional area at the top respectively.

The volume of lumber pieces recovered from the log was measured and calculated as a percentage of LR from the conversion process. The WWG per log was the difference between the total volume of a log and the volume of recovered lumber. The data obtained were analyzed and presented using frequency and percentage with the aid of a statistical package for social science (SPSS) and charts were presented using Microsoft Excel, 2016.

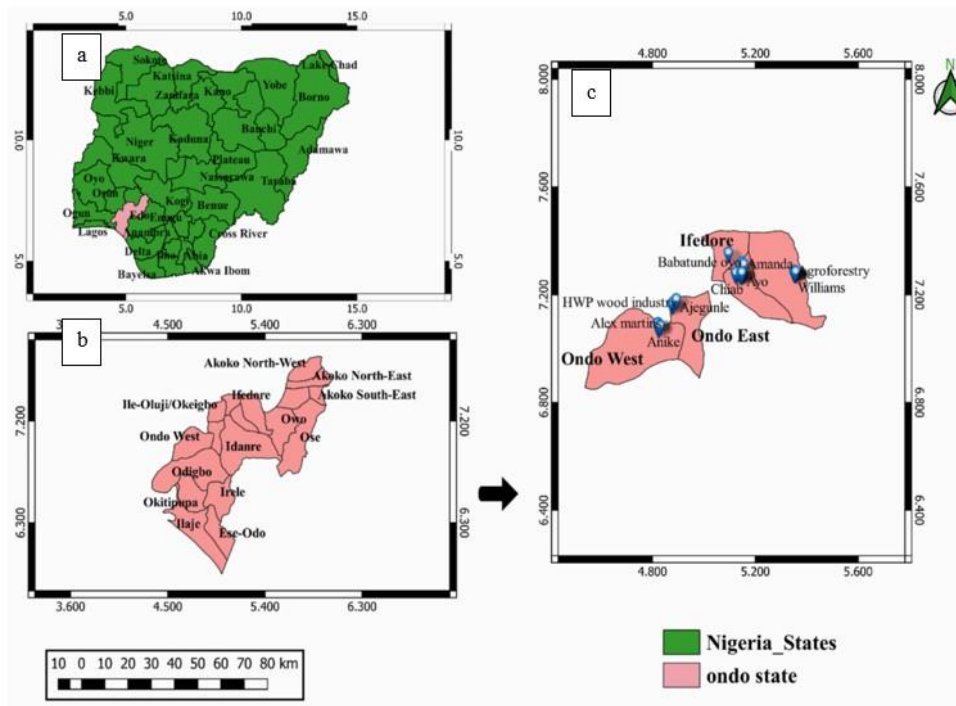


Figure 1 (a) Map of Nigeria indicating Ondo State

Figure 1 (b) Map of Ondo State showing all the local government areas (LGAs)

Figure 1 (c) Locations of the 23 mills

Table 1: The GPS location of sawmills visited in Ondo State (Field survey)

S/N	Local Government	Name of Sawmills	G.P.S Location		Scale
			Latitude	Longitude	
1	Akure South	Aflag	7.32807	5.10891	Large
		Amanda	7.28492	5.16786	Large
		Elegusi	7.25087	5.15698	Small
		Iseoluwa	7.25507	5.16356	Medium
		Adeniran	7.25349	5.1372	Small
		Okunbo	7.25422	5.16067	Medium
		Ayo sawmills	7.25078	5.16512	Medium
		Chiab	7.25286	5.13652	Small
		Babatunde oyo	7.29167	5.1614	Medium
		Ebube Sawmills	7.25306	5.13683	Medium
2	Akure North	Holy Sawmills	7.24652	5.15748	Medium
		Tunji	7.25272	5.3695	Medium
		Agro-Forestry	7.25967	5.36396	Large
		Williams	7.25887	5.36506	Small
		Azeez Sawmill	7.259	5.36481	Small
3	Ondo West	Elemo Sawmill	7.25772	5.3703	Large
		Divine Grace	7.25814	5.36446	Small
		Akinfayomi	7.0661966	4.8349194	Small
		Akinbolaji and Sons	7.049188	4.8369736	Medium
4	Ondo East	Anike	7.057565	4.8426903	Small
		Alex martins Saw	7.0651521	4.8342368	Small
		HWP Wood Industry	7.1424775	4.893368	Large
		Orbit Wood Industry	7.1360524	4.890516	Large

3. Results

3.1 Sawmill distribution in Ondo State

Figure 2 reveals the distribution of sawmills in the Ondo State LGA obtained from primary data sources. It shows that 57 sawmills were found in Akure South and Owo respectively, 45 in Okitipupa, 44 in Idanre, 42 in Akure North, 40 in Odigbo, 23 in Ose, 13 in Akoko South West, 12 in Akoko Northwest, 10 sawmills each were established in Akoko North East, Ifedore, Ondo West, and the least number of sawmill are in Akoko south East with 4 sawmills.

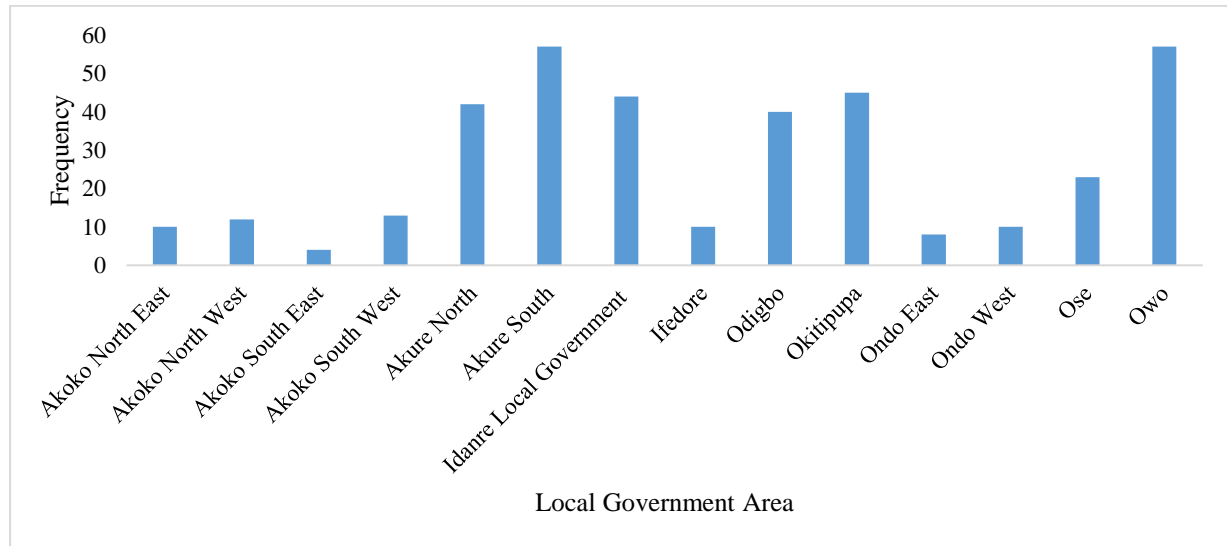


Figure 1: Distribution of sawmills in Ondo states (Sourced: Record of the Ministry of Forestry, Ondo State, Nigeria)

Akure South LGA has the highest number of sawmills (Figure. 2). This finding shows the distribution of sawmills in Akure South Local Government, Ondo State, Nigeria. 78% of sawmills are sighted on Ondo Road, 6.8% on Ilesha Road and Oda Road, 3.4% in Ipinsa, and 1.7% are found in Oke Odu, Irese, and Adofure respectively. Likewise, most sawmills in Akure South are small and medium, while few are categorised as large-scale. Also, the current status of the sawmills showed that in Ondo Road most of the sawmills are functioning, while 76.3% of the sawmills use the band saw machine (CD6) for the conversion of logs, 10.2% use circular saw and band saw machine, 6.8% of the sawmills use a circular saw and multiple edgers, and 5.1% uses multiple edgers.

3.2. Demographic Characteristics of Sawmills in Ondo State

The results of demographic characteristics of sawmills assessed in Ondo State show that 43.3% of sawmills in the four LGAs are established in Akure South, 33.3% in Akure North, 13.3% in Ondo West, while 10% are sighted in Ondo East. Table 2, revealed that 37.9% of the sawmills are classified as small and medium scale respectively, while most of the workers in the sawmills and wood industries range from 31 to 40 years. The majority of the workers claimed to have a formal education. The finding shows that 41.7% of the sawmill workers earn above #50,000 as monthly income, and 20.8% earn #41,000 - #50,000. Likewise, 32% have worked with the wood industries for 11-20 years and 21 - 30 years respectively. A large amount of these results was obtained from the managers of the wood industries.

Table 2: Demographic characteristics of Sawmills in Ondo State (Source: Field survey)

		Percent (%)
Local Government Area	Ondo West	13.3
	Ondo East	10
	Akure South	43.3
	Akure North	33.3
	Total	100
Scale	Small	37.9
	Medium	37.9
	Large	24.1
	Total	100
Age	21-30	11.5
	31-40	42.3

	41-50	34.6
	>60	11.5
	Total	100
Educational Background	Primary	17.9
	Secondary	53.6
	Tertiary	28.6
	Total	100
Monthly Income	10,000 - 20,000	12.5
	21,000 - 30,000	8.3
	31,000 - 40,000	16.7
	41,000-50,000	20.8
	above 50,000	41.7
	Total	100
Working experience	<5 years	12
	6-10 years	20
	11-20 years	32
	21 - 30 years	32
	above 50 years	4
	Total	100
Department in the Wood Industry	Loggers	6.7
	Maintenance	3.3
	Sawmill	13.3
	machine operator	16.7
	Manager	33.3
	Director	13.3
	Supervisor	3.3
	Contractor	6.7
	Log Supplier	3.3
	Total	100

3.3. Assessment of Sawmills and Wood Industries in Ondo State

Determination of Sawmill Capacity of Production

The assessment of sawmills in the four LGAs revealed that a large number of sawmills in Ondo State operate on a small scale of production level. For primary log conversion, 41% of the sawmills have just a single band saw, 37% have two and only 11% have 3 or 4 bandsaws as shown in Figure 3a. For secondary lumber conversion, 71% of the sawmills have only one circular saw, 17% have 2 circular saws and 12% have 3 circular saws as shown in Figure 3b.

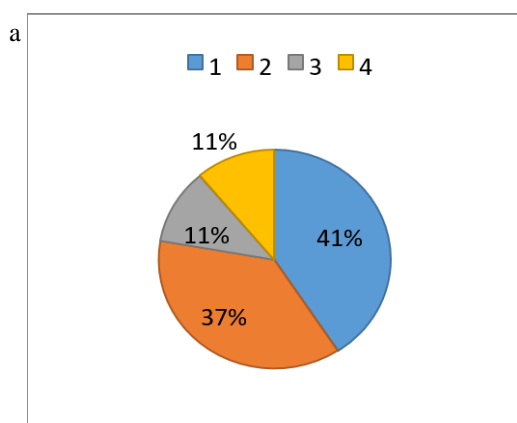


Figure 3: (a): Band saw

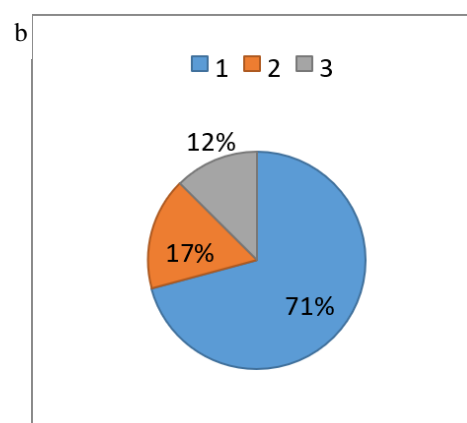


Figure 3: (b): Circular Saw

Figure 3 (a) Keys: 1: Mills with one band saw; 2: Mills with two band saws; 3: Mills with three band saws; 4: Mills with two band saws. Figure 3 (b): 1: Mills with one circular saw; 2: Mills with two circular saws; 3: Mills with three circular saws (Source: Field survey).

3.4. Storage Capacity

The results of the log storage capacity of sawmills in Ondo State are illustrated in Figure 5, 67% of the sawmills log yards have a small size land area and can only store about 350 logs, 25% have a medium size, and 8% are a large size that can store more than 1000 logs as shown in Figure 4a. Likewise, 67% of sawmills received more than 5 trucks loaded with logs monthly as shown in Figure 4b, while 63% of the sawmills processed above 20 logs in a day as shown in Figure 4c, and 64 % of sawmills depend on individual and contractors for supplying of logs, 21 % obtained their logs from forest reserves, while 7% depends on both individual and reserves for the supplying of logs as shown in figure 4d.

3.5. Assessment of Wastes Generated from Sawmills

The study revealed that wastes generated by these sawmills consist of sawdust, wood offcut, slabs, trimmings, and bark of logs of wood as shown in Figure 5. Wastes generated from these sawmills are of different (mixed) species. Based on the classification, these sawmills regarded sawdust as the only waste generated and others such as slab, trimmings, and offcut as residues because of their potential to be reused.

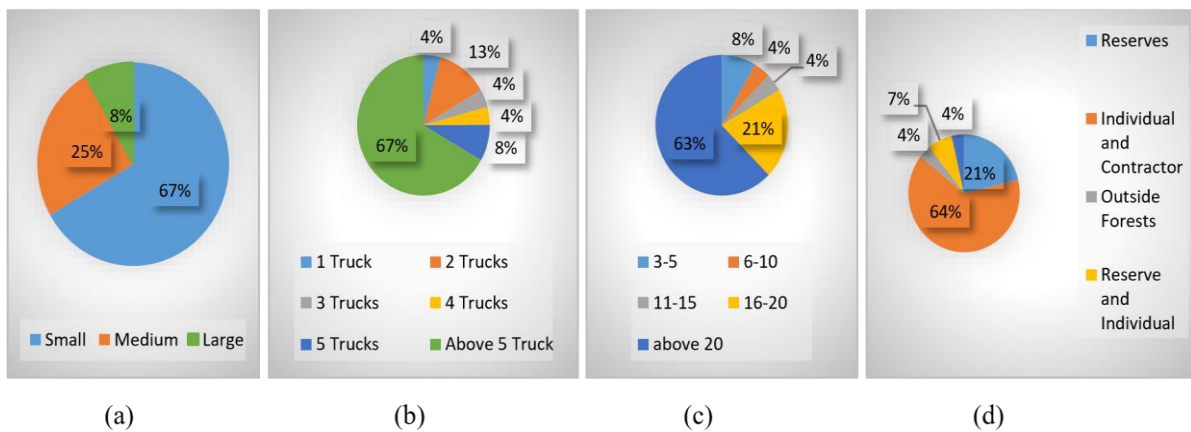


Figure 4: (a) Log yard storage capacity; (b) Log received per month; and (c) Number of processed logs into sawn timber (Planks) per day; d) Source of logs for the mill (Source: Field Survey)

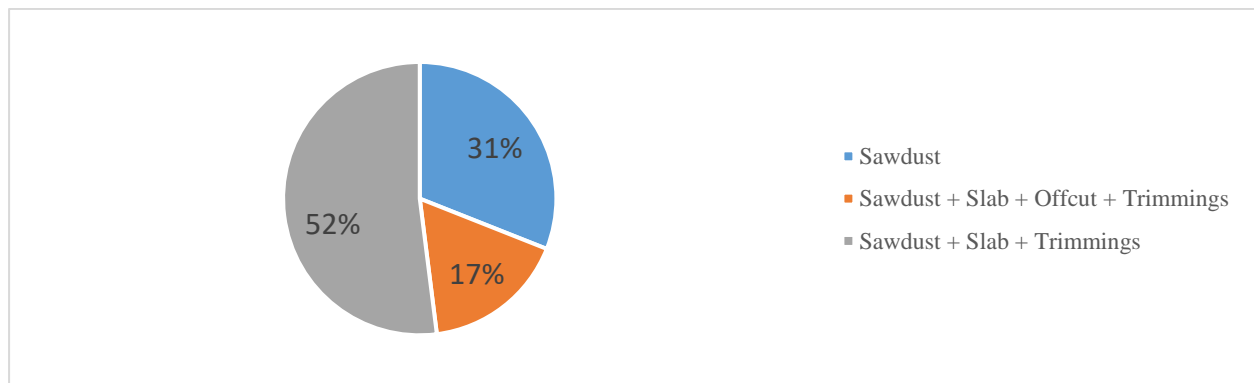


Figure 5: Mixed species Types of wastes Generated from sawmill activities (Source: Field Survey)

3.6. Lumber Recovery

The average percentage of wood waste generated per sawmill was 44%, while the average lumber recovered was 56%. There are significant variations in lumber recovery between small-sized mills in Ondo State. The low efficiency in lumber recovery (Table 3) and high wood waste generated were attributed to poor maintenance of conversion machines and poor operator skills.

Table 3: Type of machine, lumber recovery, % wood waste generated, and sawing pattern of selected sawmills in Ondo State

Sawmill Code	Type of Machine	% LR Lumber recovered	% WWG Wood waste generated	Sawing patterns
1	CDC	49.00	51.00	Keating
2	CDC	64.00	36.00	Through & Through
3	CDC	52.00	48.00	Keating
4	CDC	63.50	37.50	Through & Through
5	CDC	59.00	41.00	Keating
6	CDC	54.00	46.00	Keating
7	CDC	49.00	51.00	Keating
8	CDC	52.00	48.00	Keating
9	CDC	46.50	53.50	Through & Through
10	CDC	58.00	42.00	Through & Through
11	CDC	55.00	45.00	Keating
12	CDC	53.00	47.00	Keating
13	CDC	56.50	43.50	Keating
14	CDC	57.00	43.00	Keating
15	CDC	59.00	41.00	Keating

Note: CDC (Cyclone Dust Collection) is the Manufacturer's name for the dimension sawing machine used in the mill with the device that collects dust and chips during operation.

3.7. Distribution of the volume of Lumber recovered

The distribution of logs and lumber volume recovery per month in fourteen (14) LGAs in Ondo state, Nigeria is illustrated in Figure 6. The total volume of wood logs processed per month in Akoko North East is 420.01 m³, Akoko North West is 540.01 m³, Akoko South East is 160.00 m³, Akoko South West is 620.01m³, Akure North is 2180.04 m³, Akure South is 3160.06 m³ Idanre is 1860.04 m³, Ifedore is 420.01m³, Odigbo is 2560.05 m³, Okitipupa is 2320.05 m³, Ondo east is 320.01m³, Ondo west is 420.01 m³, Ose is 1140.02 m³ and Owo is 2820.06 m³. The results also revealed that Akure South has the highest total lumber recovery of 1896 m³, while Akoko South East has the least lumber recovery of 96.00 m³. Likewise, Akure South generated the highest volume of wood waste of 1264.03 m³ per month with an estimated volume of sawdust generated 632.01 m³, followed by Owo with a total wood waste of 1128.02 m³ with an estimated sawdust of 564.01m³. Odigbo had a total wood waste of 1024.02 m³ with estimated sawdust generated of 512.01 m³, Okitipupa local government with a total wood waste of 928.02 m³ with an estimated 464.01m³ of sawdust generated, Akure North with total wood wastes of 872.02 m³ had 436.01m³ of sawdust generated, Idanre with total wood wastes of 744.02 m³ and 372.01m³ of sawdust, Ose local government with total wood wastes 456.01 m³ and 228.01 m³ of sawdust, Akoko southwest with total wood wastes of 248.01 m³ and 124.00 m³ of sawdust. Akoko North West with 248.01 m³ volume of wood waste and 124.00 m³ of sawdust while Akoko Northeast local government generated 168.00 m³ of total wood waste and 84.00 m³ of sawdust. Ondo West local government had total wood waste of 128.00 m³ and 64.00 m³ of sawdust while Ondo East generated total wood waste of 64.00 m³ with an estimated sawdust of 32.00 m³.

The illustration in Figure 7 shows the distribution of the wood wastes generated in a month from the sawmills in the four LGAs visited. Akure South generated the highest volume of wood waste 256.01m³ with an estimated 128.00m³ of sawdust, and Akure North generated total wood waste of 136.00m³ with an estimated 68.00m³ of sawdust. Ondo West generated a total wood waste of 72.00m³ with an estimated sawdust of 36.00m³ while Ondo East generated a total wood waste of 64.00m³ with an estimated volume of 32.00m³ sawdust.

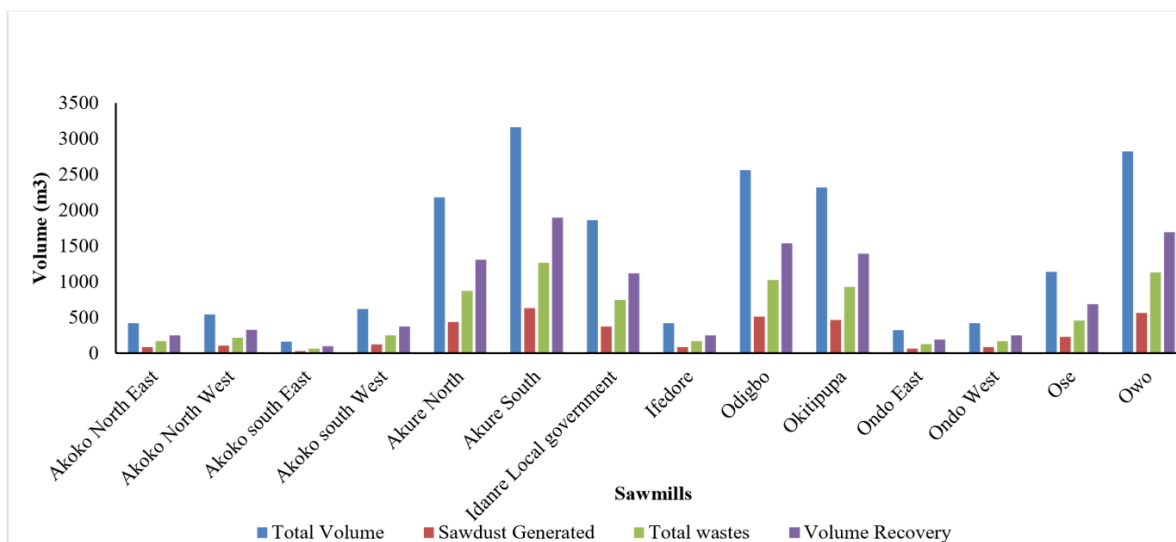


Figure 6: Assessment of wood waste generated and volume recovery from sawmill activities in Ondo state sawmills

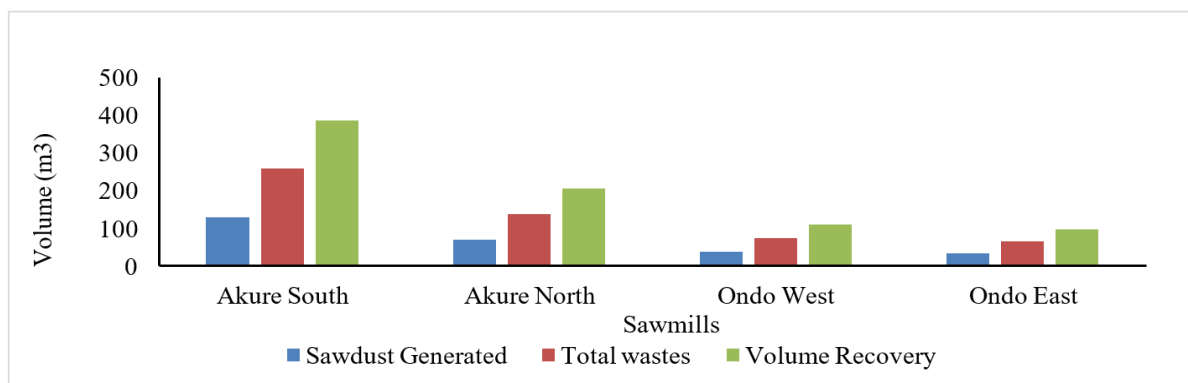


Figure 7: Wood wastes generated and lumber volume recovery from sawmill activities in Ondo State sawmills

3.8. Wastes Management Techniques

The results presented in Figure 8a show that 86% of these sawmills evacuate their wastes manually and 14% mechanically. In Figure 8b, 71% of these sawmills dispose of their waste by burning, 17% convert or reuse the waste, 8% dump it on composting sites and 4% recycle their waste. 79% of these sawmills agreed that burning wastes as a means of disposal is not effective as shown in Figure 9a. Wood waste generated in sawmills cannot be eliminated but can be significantly reduced by improving management techniques. Wood wastes are also used in the production of mosquito coils, preparation of chicken beds (Plate 1), and culturing mushrooms. The report however showed that most of the sawmills give out their sawdust for free (fig. 10b) while other forms of waste such as wood off-cut, slabs, and trimmings are sold. The price of 2000kg (full Dyna lorry load) wood slabs ranges from #6000 to #10,000 in Ondo state.

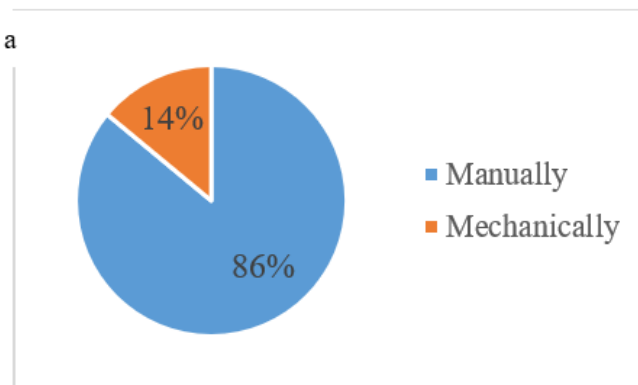


Figure 8: (a) Methods of Wastes Collection

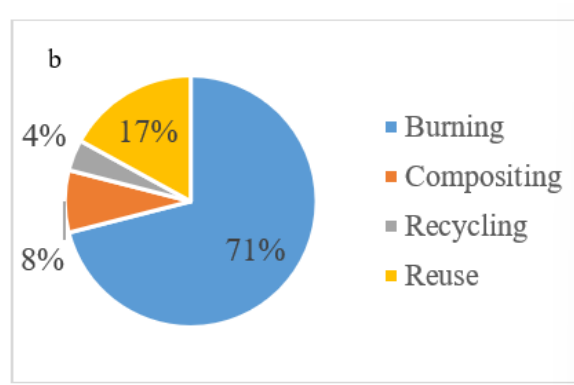


Figure 8: (b) Means of waste disposal



Plate 1: Collection of wastes for chicken Bed (field survey)

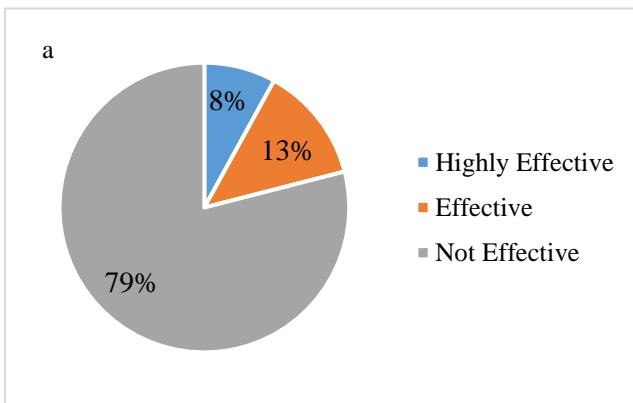


Figure 9: (a) Effectiveness of methods of waste disposal

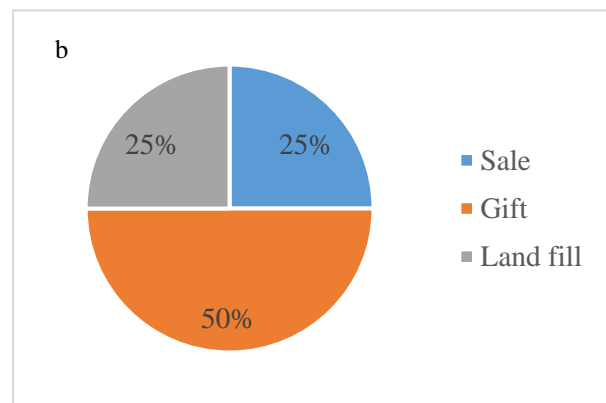


Figure 9 (b): Other uses of wood wastes

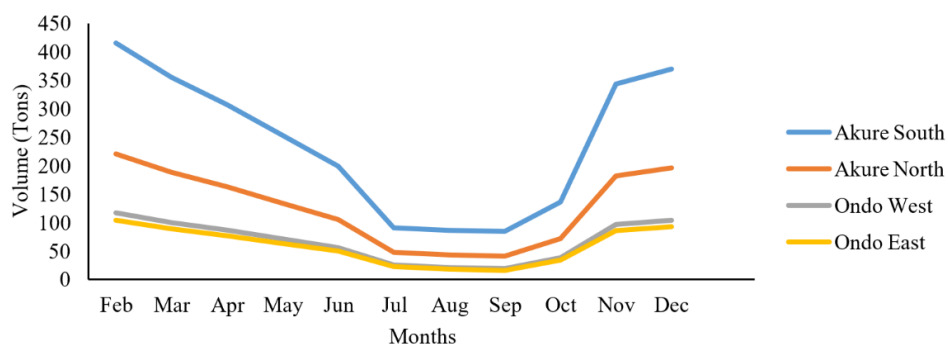


Figure 10: Seasonal Availability of wood wastes

The monthly cost of waste disposal for 48 sawmills was #5,000-10,000. 40 sawmills spent #11,000-20,000, 8 spent above #20,000, and 4 sawmills spent less than #5,000 monthly.

Seasonal Availability of Wood Wastes

The results presented in Figure 10 show the seasonal availability of wood wastes in Ondo State. There is a reduction in the volume of wood waste available from June to September due to the supply of logs that reduced drastically during the rainy season.

3.9. Promptness of Supply of Feedstock to Gasifier Plant

The results of the study have proved the availability of wood wastes in Ondo State at various degrees. However, worthy of mention is the promptness in the supply of the waste in the form needed by the gasifier when required. To

ensure a sustainable supply of this waste, Ondo State has been classified into three major groups (Figure 11) based on nearness to the Gasifier plant:

Group A: Close to Gasifier Plant

Sawmills in five LGAs namely; Akure South, Akure North, Owo, Ose, Ondo West, Ifedore, Ondo East, and Idanre have been identified as points where materials could be sourced within the shortest possible time and supplied to the base.

Group B: Distance Away from the Gasifier

This group is further divided into two;

B1. In the Northern Zone, All the sawmills in Akoko South West, Akoko North East, Akoko South East, and Akoko North West are in this category. It is suggested that a collection point be created at Ikare Akoko before transportation to Akure.

B2. The Southern Zone, All the sawmills in Odigbo, and Okitipupa are in this category. It is suggested that a collection Centre be created at Ore town before transportation to Akure.

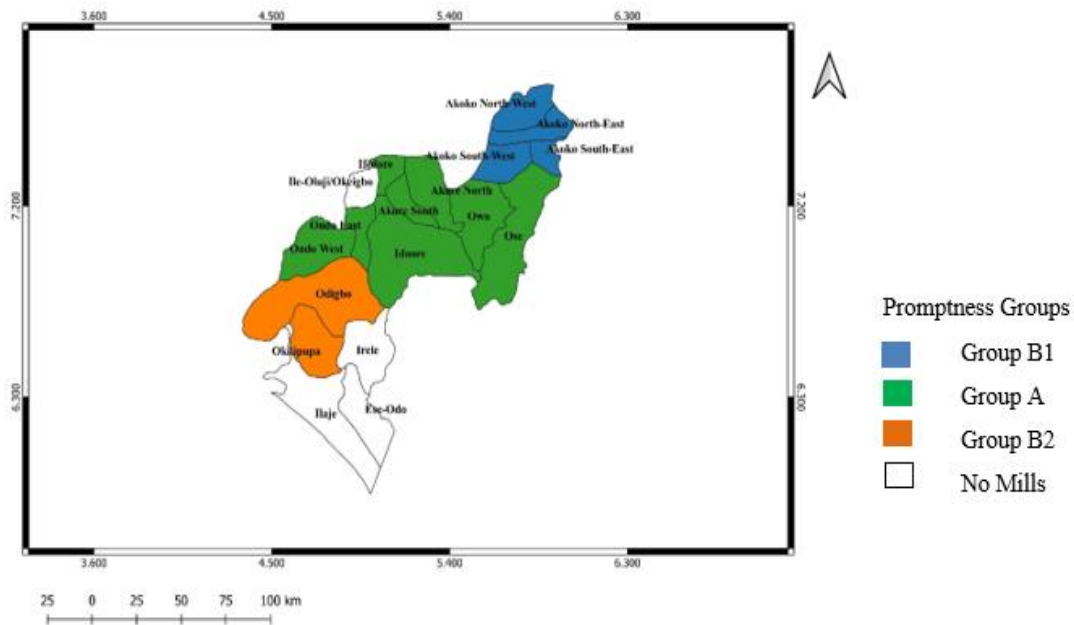


Figure 11: Map showing the Promptness of Supply of Feedstock to the Gasifier Plant

Keys: Group A: LGAs closer to the gasifier; Group B1 and B2: LGAs distance away from the gasifier; No mills are LGAs in Ondo State without a sawmill.

4. Discussion

Literature Review

This literature review (Table 4) highlights the critical role of renewable energy sources and sustainable practices in addressing global energy and environmental challenges. Renewable power sources are increasingly recognized as viable solutions to reduce dependency on fossil fuels and mitigate their environmental impacts (B.P. Economics, 2018; Newell and Raimi, 2020). However, the adoption of energy-efficiency measures is often impeded by high investment costs, a barrier consistently reported across decades of research (Fleiter et al., 2012; Hirshberg, 1976; Faiers and Neame, 2006). While sustainable practices such as energy efficiency improvements and waste reduction can lower production costs and enhance resource utilization (Hannan et al., 2020; Pimenov et al., 2022), the lack of consensus on strategies for implementing RERs remains a significant challenge to achieving the United Nations Sustainable Development Goals (Olabi et al., 2023; Wang et al., 2022; He et al., 2022).

In Nigeria, wood waste mismanagement represents a serious environmental threat, despite its abundance (Sambo, 2009; Ogunwusi, 2014; Owoyemi et al., 2016; Akhator et al., 2017; Nwankwo et al., 2023). Transforming wood waste into biomass for bioenergy presents an opportunity to address this issue while providing a sustainable energy source, particularly in the building sector. This solution is especially relevant in Nigeria, where rapid population growth has led to increased energy demands (Maier, 2022; Akintande et al., 2020; Xie et al., 2023; Izuora, 2022). By integrating innovative energy strategies and resource optimization, institutions in Nigeria can simultaneously tackle environmental challenges and enhance energy security.

Table 4: Literature review

Findings	Literature
Renewable power generation sources are increasingly identified as viable solutions to reduce; the heavy reliance on fossil fuels	B.P. Economics, 2018; Newell and Raimi, 2020
Sustainable practices such as energy efficiency improvements, waste reduction, and resource optimisation can lead to substantial reductions in the cost of production.	Ogunwusi, 2014; Akhator et al., 2017; Hannan et al., 2020; Pimenov et al., 2022; Tormade and Chiekiezie, 2024.
The high investment cost is a key factor impeding the adoption of energy-efficiency measures.	Hirshberg, 1976; Fleiter et al., 2012; Faiers and Neame, 2006
The rise in the use of Renewable Energy is pivotal to achieving the United Nations SDGs, but effective strategies for their implementation remain contested.	Olabi et al., 2023; Wang et al., 2022; He et al., 2022
Wood waste mismanagement is a serious environmental threat owing to its availability in Nigeria.	Sambo, 2009; Ogunwusi 2014, Owoyemi et al., 2016; Akhator et al., 2017; Nwankwo et al., 2023
The utilization of wood waste as biomass for bioenergy offers a sustainable energy solution, addressing both environmental concerns in the building sector and Nigeria's rising energy demands driven by population growth.	Maier, 2022; Akintande et al., 2020; Xie et al., 2023; Izuora, 2022

Considering the distribution of sawmills in Akure South LGA with the potential of generating high quantities of wood waste in each region, the efficient utilization of this wood waste for energy generation will play a pivotal role in addressing the environmental and energy challenges posed by these regional disparities (Bais-Moleman et al., 2018).

This finding of the sawmill production capacity indicates a notable lack of advanced and high-capacity machinery within the primary conversion stage of mills within the study area. This suggests that their production is on the small to medium production capacity. This is in line with the study of Kehinde et al. (2010) that both small- and medium-scale dominated sawmills in Ondo and Osun states, Nigeria. On average, less than 10% of these mills are capable of storing more than a thousand logs in their log yards for future production when the harvest of logs from the forest is difficult and the majority of the mills are capable of converting more than twenty logs per day as they depend on individuals and contractor for log supply. The study showed that the supply of logs reduced drastically during the rainy season. It also revealed that log haulage in the state was also affected by Government policy, this is in agreement with the findings of (Omole and Imoh, 2011) that the sustainability of the forest estate is largely dependent on government policy. Majorly, wastes generated from these sawmills are of different mixed species and regarded sawdust as the dominant waste which can be gotten with no cost while others such as slabs, trimmings, and offcuts as residues because of their potential to be reused are made available with a price. This corroborates with the findings of Ogunbode et al., (2013) and Akinbode and Olujimi (2014).

The findings from this study showed that In Ondo State, improper handling of wood waste poses a major environmental risk as wood waste management practices, which include the collection, disposal, recycling, and reuse of wood waste, are ineffective and inadequate, as evidenced by the obvious disposal of wood waste on streets, in water bodies, and open air. This study corroborates the work of Nwankwo et al., 2023 in Niger State, Nigeria improper wood waste management practices in the state also present major environmental risks. The lack of efficient systems for wood waste collection, recycling, and disposal threatens not only environmental balance but also the sustainability

of timber forests and public health. Wood wastes are generated in the day-to-day wood processing activities in sawmills and furniture manufacturing industries (Owoyemi et al., 2016; Akhator et al., 2017; Nwankwo et al., 2023). These processing activities range from conversion of logs, ripping, planning, turning and sanding. A very large volume of the log turns out to be wasted during primary conversion as lumber recovered is less than 60% with a significant difference between the types of mills as those with wear-out conversion machines operating on the small scale level tend to produce more waste during conversion. The low mean conversion efficiency of 56% recorded for the mills is in the same range as earlier reports (Badejo, and Giwa, 1985; Fuwape 1986; Oluoti 2014). Peterson et al., 2015 described that the reduction of the magnitude of wood supply by mills depends largely on the volume and sizes of wood supplied to the mill, and other competing management objectives. These large amounts of wood waste generated during wood processing activities are mostly dumped on allocated sites to decay. This is not the case for developed countries, where all types of waste have designated dumpsites and storage facilities where they are sorted, treated and recycled or reused. For the effective utilization of wood waste in bioenergy generation in Nigeria the waste management definition of Ormondroyd et al. (2016) must be given full consideration stating that wood waste management is the collection, refurbishing, recycling, reuse and proper disposal of wood residues. Studies have shown that wood waste recycling and reuse will help create a sustainable environment. However, numerous wood mills in Nigeria have yet to adopt advanced processing of wood waste due to the high cost of the technology and the limited financial returns from processed wood waste (Larinde et al., 2014). The study by Rawat et al. (2023) revealed that maximizing the lumber recovery rate of *Cupressus lusitanica* in Ethiopia can increase sawmill profitability, reduce climate change impacts, and promote sustainable forestry and biodiversity conservation.

An assessment of sawmills and wood industries in Ondo State reveals that 84% are willing to collaborate with stakeholders who utilize wood waste, particularly sawdust, as raw materials or for waste management purposes. This willingness extends to offering these materials at minimal or no cost to enhance the efficiency and sustainability of waste management efforts. This is in line with the finding of Nnaji and Udokpoh (2022) that Sawdust is the most common type of wood waste in the Enugu Timber Market, with open dumping and burning being the most prevalent methods of disposal, causing negative environmental effects and health problems. The study of Rominiyi et al. (2017) agreed that all readily recovered wood waste could be absorbed by the industry for energy supply. This led to greater attention being paid to the possibility of utilising wood wastes in energy generation which otherwise would be wasted. Also, solving the problem of increasing costs, crisis and depletion of energy from conventional sources over the past few years has reawakened interest in the development of alternative sources of energy. Mydlarz and Wieruszewski (2022) further explained in their study that sawmills can use wood waste and by-products for energy, promoting a circular economy and economic efficiency, regardless of government decisions when considering the potential and possibilities of using wood waste and wood by-products generated at various stages of production in companies of the wood industry for energy purposes. The article demonstrates that, regardless of government policies on environmental protection, institutions have the autonomy to adopt pro-environmental practices as part of their operations. This study highlights the feasibility of its objective, emphasizing the abundant availability of wood waste in Nigeria. It suggests that institutions such as the Federal University of Technology, Akure, along with other academic establishments, can sustainably generate electric energy entirely from wood waste collected within Akure and its surrounding areas. The supply of logs is limited because of changes in seasons as wood supply to the mills is reduced drastically during the rainy season. The study by Okon (2018) states that sustainable wood harvesting in Nigeria's tropical rainforest requires proper management methods, including the construction of landing sites and training for operators, to minimize damage and promote forest regeneration. Therefore, to ensure that the Gasifier runs non-stop, collection of wood waste for feedstock should be done regularly and more vigorously during the dry season and deposited to the three location points (i.e. Akure, Ikare, and Ore) and move on schedule from the two outer locations to Akure. Regular stocking will ensure enough materials are in stock for use during the rainy season when sawmill activities are at the lowest ebb.

The production and utilization of alternative energy sources are increasingly gaining attention. With traditional energy sources like gas, oil, and coal being non-renewable and finite, the need to explore sustainable alternatives has become more pressing. The abundant generation of wood waste in Nigeria presents a significant opportunity for institutions like the Federal University of Technology, Akure, to establish a reliable source of renewable energy. With proper

collection, processing, and utilization of wood waste, including sawdust and offcuts from local sawmills, the institution can create a sustainable energy system that addresses both environmental and energy challenges. This approach not only reduces dependence on non-renewable energy sources but also mitigates the environmental hazards associated with improper wood waste disposal, such as pollution and deforestation, positioning the institution as a leader in renewable energy innovation. Farjana et al. (2023) described that all wood wastes have great potential to produce energy while reducing climate change impact, with hardwood and softwood products showing the most beneficial aspects. Carbon dioxide emissions from traditional energy sources are significantly higher than those from biofuels, making them a promising alternative energy source (Farjana et al., 2023; Opara, 2021; Kim and Song, 2014).

5. Conclusions

The generation of wood waste is inevitable but can be reduced through improved management techniques. This study revealed that a larger percentage of the sawmills in Ondo State operate on a small scale and generate large quantities of waste daily. The seasonal variations in the volume of log conversion affected the volume of wood waste.

The result showed that 40 to 44% of the total volume of a log converted in the mills ends up as wood waste. The high quantity of wood waste and low lumber recovery were functions of the shape of the log, the size of the log, and the conversion technique. The sawmills in Akure South local government have the highest log conversion capacity and the largest quantity of wood waste. The high values of wood waste generated per sawmill and low values of lumber recovery implied that the log conversion technique in the state is generally poor. This wood waste generated is also not efficiently managed for optimum utilization. Most of the mills regarded only sawdust as waste while other residues such as wood cut-off, slabs, and bark of logs of woods are sold out. The sawdust is disposed of at low costs for domestic uses, dumped in landfills, or burnt at mill sites. This study confirmed that the wood wastes can be used as feedstock in the mini-grid gasifier for generating electricity at the Federal University of Technology, Akure.

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Ethics Approval

The Ethics Committee of the Federal University of Technology Akure (TETF/ES/DR&DCE/NRF2020/CC/36) granted ethics approval for this project, as the research was conducted according to the ethical principles and guidelines outlined by the institution. No upgraded ethical clearance of the specific project activity was envisaged or compelled.

Conflict of interest:

The author(s) declare that there is no competing interest.

References

- Akhator, P., Obonor, A., & Ugege, A. (2017). Nigeria wood waste: A potential resource for economic development. *Journal of Applied Science and Environmental Management*, 21(2), 246–251.
- Akinbode, T., & Olujimi, J. (2014). Effects of sawmill wastes in residential areas of Ogbese and Akure Townships, Ondo State, Nigeria. *International Journal of Innovation and Scientific Research*, 9, 399–409.
- Akintande, O., Olubusoye, O., Adenikinju, A., & Olanrewaju, B. (2020). Modelling the determinants of renewable energy consumption: Evidence from the five most populous nations in Africa. *Energy*. <https://doi.org/10.1016/j.energy.2020.117992>
- Alagbada, O. R. (2021). Lumber recovery efficiency of some selected sawmills in Ishiagu, Ebonyi State, Nigeria. *Journal of Research in Forestry, Wildlife & Environment*, 13(4), 101–108.
- Alviar, G. O. (1983). Sawmilling industry in Nigeria. Field Document No. 17. Rome, Italy: FAO.
- Badejo, S. O., & Giwa, S. A. (1985). Volume assessment and economic importance of sawmill wood waste utilization in Nigeria. Technical Report Savanna Series No. 50 (pp. 1–37).
- Bais-Moleman, A., Sikkema, R., Vis, M., Reumerman, P., Theurl, M., & Erb, K. (2018). Assessing wood use efficiency and greenhouse gas emissions of wood product cascading in the European Union. *Journal of Cleaner Production*, 172, 3942–3954. <https://doi.org/10.1016/j.jclepro.2017.04.153>

- Caselli, F., Ludwig, A., & Van Der Ploeg, R. (2021). No brainers and low-hanging fruit in national climate policy. Retrieved from <http://www.janakreis.de> [Accessed 16 November 2024].
- Faiers, A., & Neame, C. (2006). Consumer attitudes towards domestic solar power systems. *Energy Policy*, 34, 1797–1806. <https://doi.org/10.1016/j.enpol.2005.01.001>
- Farjana, S. H., Tokede, O., & Ashraf, M. (2023). Environmental impact assessment of waste wood-to-energy recovery in Australia. *Energies*, 16(10), 4182. <https://doi.org/10.3390/en16104182>
- Fleiter, T., Schleich, J., & Ravivanpong, P. (2012). Adoption of energy-efficiency measures in SMEs: An empirical analysis based on energy audit data from Germany. *Energy Policy*, 51, 863–875.
- Fuwape, J. A. (1986). Checking deforestation through improved wood conversion technology. In *Proceedings of the 16th Annual Conference of Forestry Association of Nigeria* (pp. 47–85).
- Gratitude, C. G., Gwiranai, D., & Muzendaa, E. (2019). A review of timber waste utilization: Challenges and opportunities in Zimbabwe. *Procedia Manufacturing*, 35, 419–429.
- Hannan, M., Begum, R., Al-Shetwi, A. Q., Ker, P., Al Mamun, M., Hussain, A., et al. (2020). Waste collection route optimisation model for linking cost-saving and emission reduction to achieve sustainable development goals. *Sustainable Cities and Society*, 62, 102393.
- He, J., Yang, Y., Liao, Z., Xu, A., & Fang, K. (2022). Linking SDG 7 to assess the renewable energy footprint of nations by 2030. *Applied Energy*, 317, 119167. <https://doi.org/10.1016/j.apenergy.2022.119167>
- Hirshberg, A. (1976). Public policy for solar heating and cooling. *Bulletin of the Atomic Scientists*, 32, 37–45. <https://doi.org/10.1080/00963402.1976.11455644>
- Izuora, C. (2022). Nigeria requires 30,000MW of electricity generation to meet current demand. Leadership Media Group. Retrieved from <https://leadership.ng/nigeria-requires-30000mw-electricitygeneration-to-meet-current-demand/> [Accessed June 29, 2023].
- Jie, H., Khan, I., Alharthi, M., Zafar, M. W., & Saeed, A. (2023). Sustainable energy policy, socio-economic development, and ecological footprint: The economic significance of natural resources, population growth, and industrial development. *Utilities Policy*, 81, 101490. <https://doi.org/10.1016/j.jup.2023.101490>
- Kanwal, S., Mehran, M. T., Hassan, M., Anwar, M., Naqvi, S. R., & Khoja, A. H. (2022). An integrated future approach for the energy security of Pakistan: Replacement of fossil fuels with syngas for better environment and socio-economic development. *Renewable and Sustainable Energy Reviews*, 156, 111978. <https://doi.org/10.1016/j.rser.2021.111978>
- Kehinde, A., Awoyemi, T., Omonona, B., & Akande, J. (2010). Technical efficiency of sawn wood production in Ondo and Osun states, Nigeria. *Journal of Forest Economics*, 16, 11–18. <https://doi.org/10.1016/J.JFE.2009.04.001>
- Kim, M., & Song, H. (2014). Analysis of the global warming potential for wood waste recycling systems. *Journal of Cleaner Production*, 69, 199–207. <https://doi.org/10.1016/J.JCLEPRO.2014.01.039>
- Kocak, E., Ulug, E. E., & Oralhan, B. (2023). The impact of electricity from renewable and non-renewable sources on energy poverty and greenhouse gas emissions: Empirical evidence and policy implications. *Energy*, 272, 127125. <https://doi.org/10.1016/j.energy.2023.127125>
- Larinde, S. L., & Aiyelaja, A. A. (2014). Production of specialty wood products from the wood waste of selected timber species generated in furniture workshops. *Journal of Production, Agriculture and Technology (PAT)*, 10,(1), 67–73.
- Maier, D. (2022). The use of wood waste from construction and demolition to produce sustainable bioenergy—a bibliometric review of the literature. *International Journal of Energy Research*, 46, 11640–11658. <https://doi.org/10.1002/er.8021>
- Ministry of Environment and Forestry. (2023). *The Record Book of the Ministry of Environment and Forestry, Ondo State, Nigeria*. Collected from the head office in Akure, Ondo State, Nigeria.
- Mydlarz, K., & Wieruszewski, M. (2022). Economic, technological as well as environmental and social aspects of local use of wood by-products generated in sawmills for energy purposes. *Energies*, 15(4), 1337. <https://doi.org/10.3390/en15041337>
- National Population Commission (NPC). (2006). *Nigerian Population Census Report*. Abuja, Nigeria: National Population Commission, pp. 21–27.
- Newell, R. G., & Raimi, D. (2020). Global energy outlook comparison methods: 2020 update. *Resources for the Future*.
- Nnaji, C., & Udokpoh, U. (2022, April). Sawdust waste management in Enugu timber market. In *3rd African International Conference on Industrial Engineering and Operations Management*. <https://doi.org/10.46254/AF03.20220087>
- Nwankwo, F. C., Okwori, O. R., Maik, M. B., & Obeta, I. C. (2023). Assessment of wood waste management practices in small and medium-scale enterprises in Minna, Niger State. *Journal of Resources Development and Management*, 90, 87–97.
- Ogunbode, E., Fabunmi, F., Ibrahim, S., Jimoh, I., & Idowu, O. (2013). Management of sawmill wastes in Nigeria: Case study of Minna, Niger State. *Global Journal of Science, Engineering and Technology Research*, 3, 34–41. <https://doi.org/10.15580/GJSETR.2013.2.012413407>
- Ogunwusi, A. A. (2014). Wood waste generation in the forest industry in Nigeria and prospects for its industrial utilization. *Civil and Environmental Research*, 6(9), 62–69.
- Okedere, O. B., Fakinke, B. S., Sonibare, J. A., Elehiafe, F. B., & Adesina, O. A. (2017). Particulate matter pollution from open burning of sawdust in Southwestern Nigeria. *Cogent Environmental Science*, 3, Article 1367112.
- Okon, K. (2018). Sustainability of wood harvesting in tropical rainforest of Nigeria. *Eurasian Journal of Forest Science*, 6(2), 44–55. <https://doi.org/10.31195/ejef.427416>
- Olabi, A., Elsaid, K., Obaideen, K., Abdelkareem, M. A., Rezk, H., Wilberforce, T., Maghrabie, H. M., & Sayed, E. T. (2023). Renewable energy systems: Comparisons, challenges and barriers, sustainability indicators, and the contribution to UN sustainable development goals. *International Journal of Thermofluids*, 20, Article 100498. <https://doi.org/10.1016/j.ijft.2023.100498>

- Oladipo, K., Felix, A. A., Bango, O., Chukwuemeka, O., & Olawale, F. (2018). Power sector reform in Nigeria: Challenges and solutions. IOP Conference Series: Materials Science and Engineering, 413, Article 012037. <https://doi.org/10.1088/1757-899X/413/1/012037>
- Oluoti, K. (2014). Nigerian wood waste: A dependable and renewable fuel option for power production. World Journal of Engineering and Technology, 2, 234–248. <http://www.scirp.org/journal/wjet>
- Omole, A. O., & Imoh, B. M. (2011). Conversion efficiency in re-saw wood processing mills of Akwa Ibom State, Nigeria. Forests and Forest Products Journal, 4, 53–60.
- Omonijo, A. J., & Matzarakis, A. (2011). Climate and bioclimate analysis of Ondo State, Nigeria. Meteorologische Zeitschrift, 20(5), 531–539.
- Opara, M. V. (2021). Cyclical use of wood waste in the production of alternative energy sources. In Materials of the All-Russian Scientific and Practical Conference: Modern Machines, Equipment and IT Solutions for Industrial Complex: Theory and Practice, 266–269. https://doi.org/10.34220/MMEITSIC2021_266-269
- Ormondroyd, G. A., Spear, M. J., & Skinner, C. (2016). The opportunities and challenges for re-use and recycling of timber and wood products within the construction sector. In Environmental Impacts of Traditional and Innovative Forest-based Bio-products (pp. 45–103). Springer.
- Owoyemi, J. M., Zakariaya, H. O., & Elegbede, I. O. (2016). Sustainable wood waste management in Nigeria. Environmental and Socio-economic Studies, 4(3), 1–9.
- Peterson, D., Dodson, E., & Harrod, R. (2015). Post-fire logging reduces surface woody fuels for up to four decades following wildfire. Forest Ecology and Management, 338, 84–91. <https://doi.org/10.1016/j.foreco.2014.11.016>.
- Pimenov, D. Y., Mia, M., Gupta, M. K., Machado, Á. R., Pintaude, G., Unune, D. R., & Wojciechowski, S. (2022). Resource saving by optimization and machining environments for sustainable manufacturing: A review and future prospects. Renewable and Sustainable Energy Reviews, 166, 112660. <https://doi.org/10.1016/j.rser.2022.112660>
- Raw Material Research Council. (1988). Report on the geographical distribution of wood and wood products industries in Nigeria.
- Rawat, Y. S., Eba, M., & Nebiyu, M. (2023). Lumber recovery rate of Cupressus lusitanica in Arsi Forest Enterprise, Ethiopia. Sustainability, 15(2), 1046. <https://doi.org/10.3390/su15021046>
- Rominyi, O., Adaramola, B., Ikumapayi, O., Oginni, O., & Akinola, S. (2017). Potential utilization of sawdust in energy, manufacturing, and agricultural industry: Waste to wealth. World Journal of Engineering and Technology, 5, 526–539. <https://doi.org/10.4236/wjet.2017.53045>
- Tormade, A. S., & Chiekezie, N. R. (2024). Driving sustainable business practices in SMEs: Innovative approaches for environmental and economic synergy. International Journal of Management & Entrepreneurship Research, 6(8), 2637–2647.
- Wang, G., Sadiq, M., Bashir, T., Jain, V., Ali, S. A., & Shabbir, M. S. (2022). The dynamic association between different strategies of renewable energy sources and sustainable economic growth under SDGs. Energy Strategy Reviews, 42, 100886. <https://doi.org/10.1016/j.esr.2022.100886>
- Xie, J., Zhu, K., Zhang, Z., Chen, X., Lin, Y., Hu, J., Xiong, Y., Zhang, Y., Huang, Z., & Huang, H. (2023). Chemical looping gasification of wood waste using NiO-modified hematite as an oxygen carrier. Energies. <https://doi.org/10.3390/en16041847>
- Sambo, A. S. (2009). The place of renewable energy in the Nigeria energy sector. In Workshop on Renewable Energy Policies, October 2009, Addis Ababa, Ethiopia.